Measurement of the Transverse Single Spin Asymmetry of $p+p^{\uparrow} \rightarrow \eta+X$ at $\sqrt{s} = 200$ GeV

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PHENIX

BROOKHAVEN NATIONAL LABORATORY

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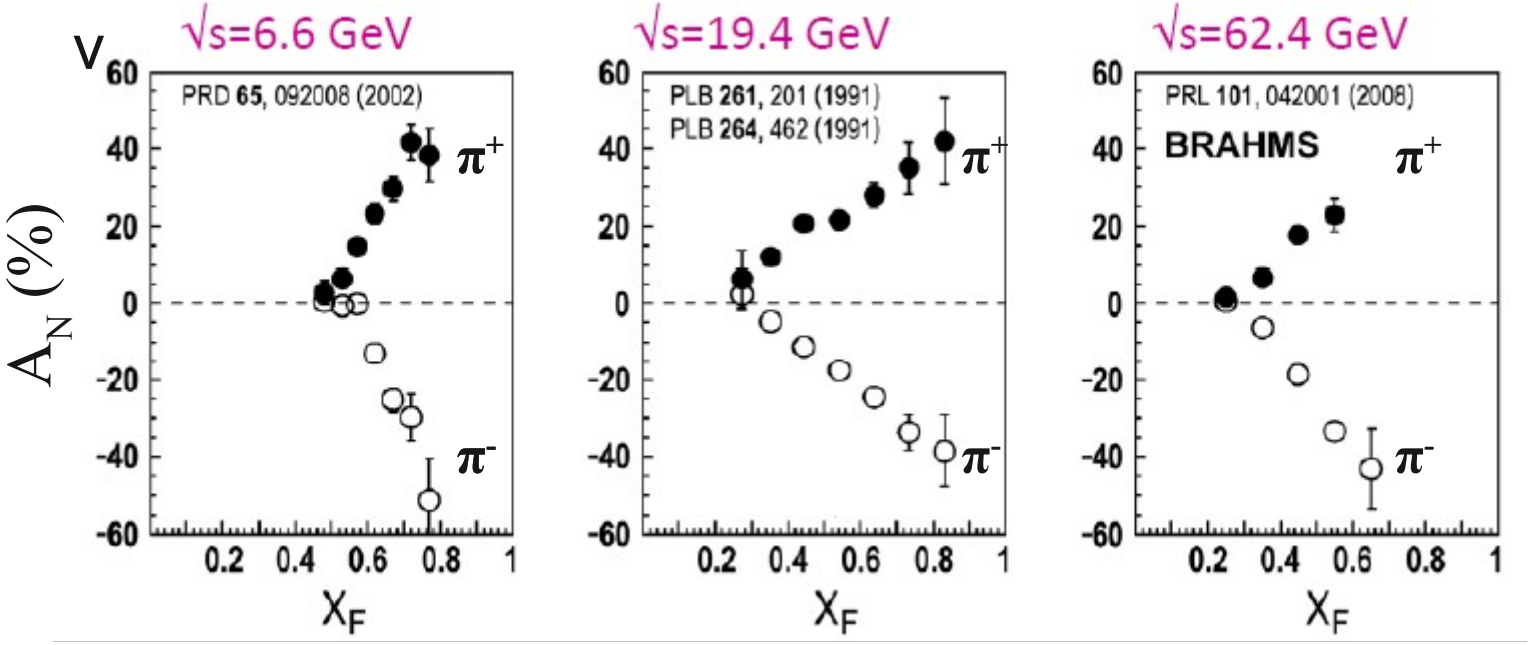
Outline

- Motivation: The $p + p^{\uparrow} \rightarrow h + X$ process and the origin of A_N
- How to Measure A_N
- RHIC and PHENIX
- Current status of η meson A_N measurement
  - Understanding our background
  - Estimated uncertainty on η meson A_N

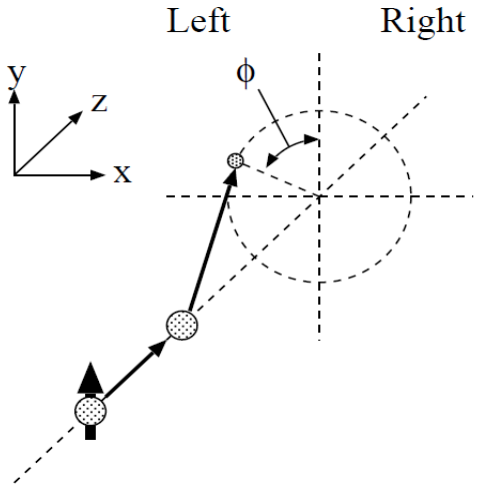
Motivation

A_N non-zero at various collision energies, various particles



$$x_F = \frac{2p_l}{\sqrt{s}}$$

i.e. fraction of proton energy given to forward momentum of hadron



Collinear pQCD at leading twist interaction has small spin dependence, i.e. no asymmetry

Can initial or final state effects produce a nonzero asymmetry?

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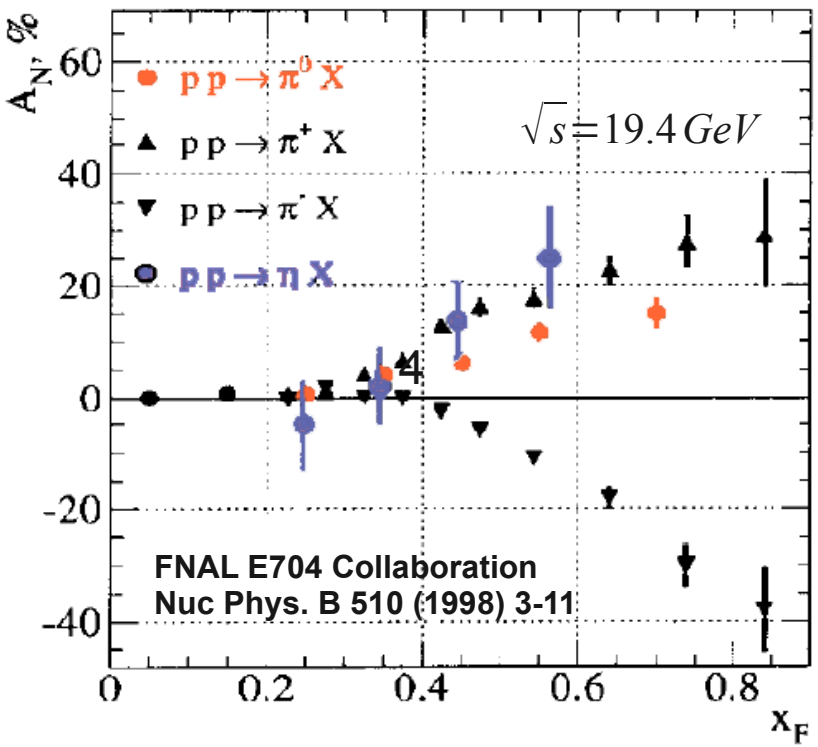
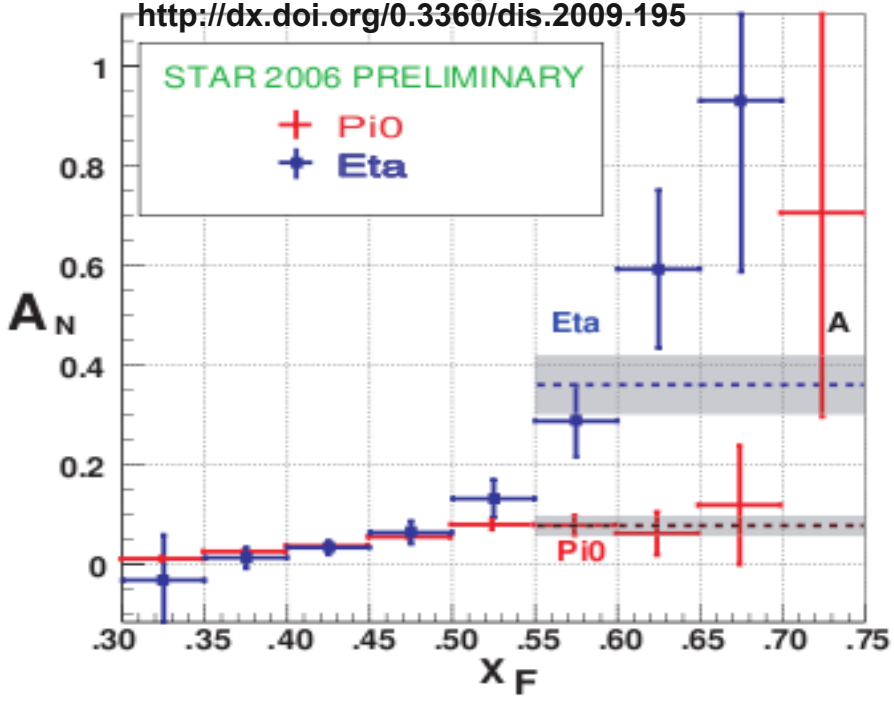
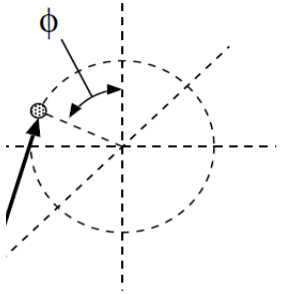


Heppelmann, DIS 2009 Proceedings
http://dx.doi.org/0.3360/dis.2009.195



of proton energy
ward momentum

ft Right



Collinear pQCD at leading twist interaction has small spin dependence, i.e. no asymmetry

Can initial or final state effects produce a nonzero asymmetry?

What is η meson A_N at $\sqrt{s}$ = 200 GeV ?

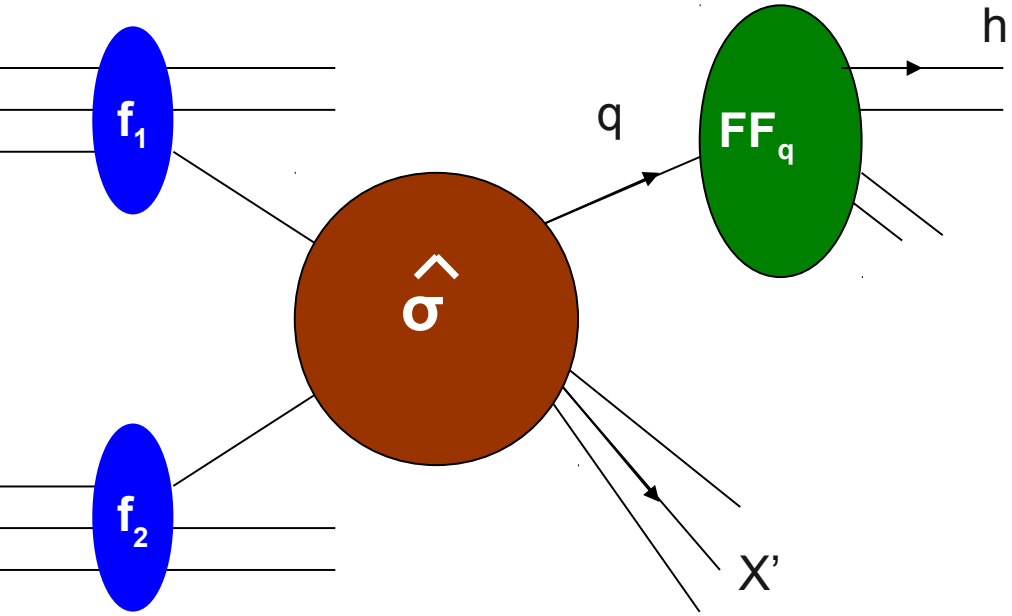
Nucleon-Nucleon collisions: QCD factorization

Proton Structure **pQCD**

$$\frac{d^3\sigma(pp \to hX)}{dx_1\,dx_2\,dz} \propto q_1(x_1)\cdot q_2(x_2) \times \frac{d^3\hat{\sigma}(q_i q_j \to q_k q_l)}{dx_i\,dx_j} \times FF_{q_k q_l}(z, p_{h,T})$$

Hard scattering

fragmentation function



- **Two partons w/ respective momentum fraction interact**
- **Hard scattering of partons**
  - Small spin dependence
- **Hard scattering of partons produce Fragments (e.g. hadrons)**
  - Different partonic processes responsible for different $p_{h,T}$ ranges of measured hadrons

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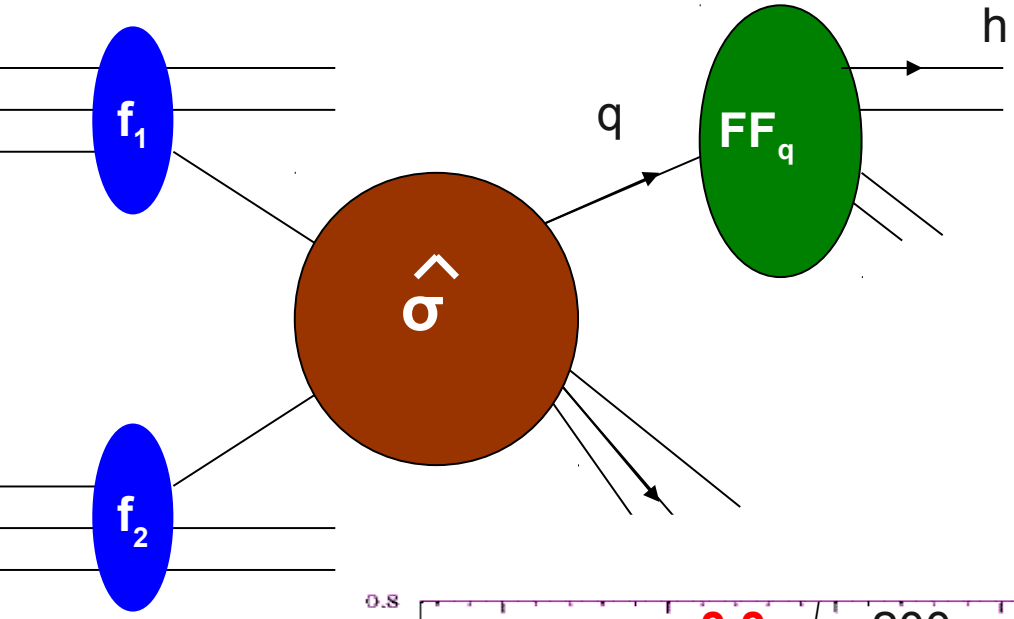

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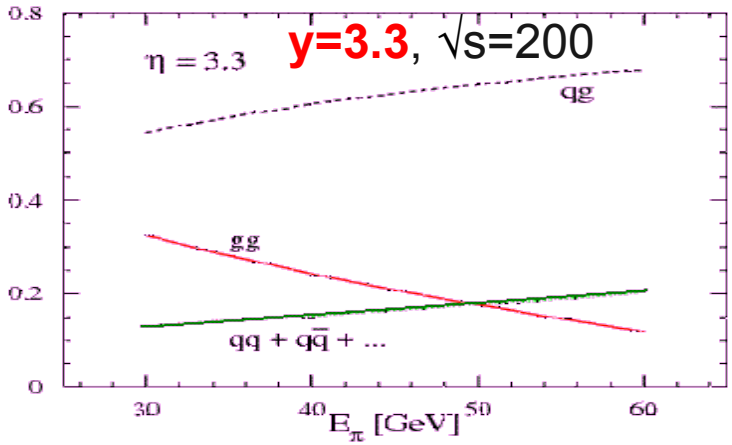


Origin of A_N from $p + p^{\uparrow} \rightarrow h + X$

Proton Structure **pQCD**

$$\frac{d^3\sigma(pp \rightarrow hX)}{dx_1\,dx_2\,dz} \propto q_1(x_1)\cdot q_2(x_2) \times \frac{d^3\hat{\sigma}^{\uparrow}(q_i q_j \rightarrow q_k q_l)}{dx_i\,dx_j} \times FF_{q_k q_l}(z,\, p_{h,T})$$

Hard scattering — **fragmentation function**

- "Transversity" quark-distributions and Collins fragmentation
  - Correlation between proton-spin and quark-spin and spin dependent fragmentation

$$A_N \propto \delta q(x) \cdot H_1^{\perp}(z,\, p_{h,T}^2)$$

- Sivers quark distribution
  - Correlation between proton spin and transverse quark momentum

$$A_N \propto f_{1T}^{\perp q}(x,\, k_T^2) \cdot D_q^h(z)$$

- Higher Twist Effects

Measuring A_N for $p+p^{\uparrow} \rightarrow h+X$

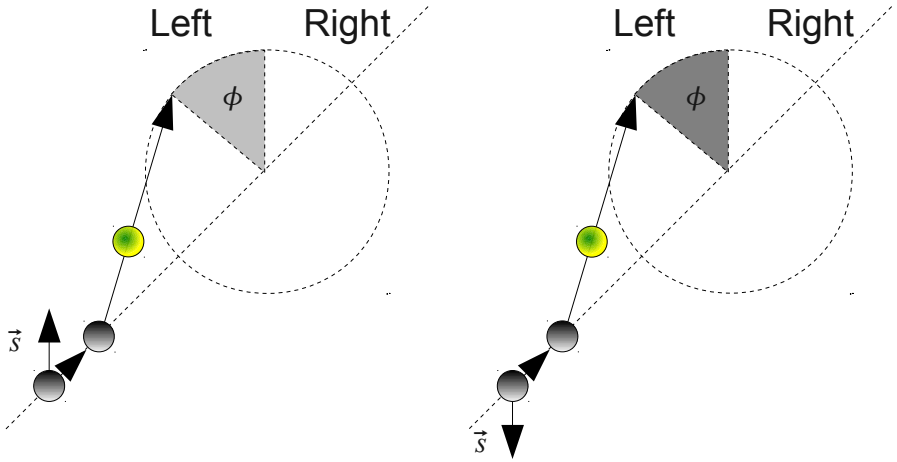
$$\frac{d\sigma(pp^{\uparrow} \rightarrow hX)}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_0 \cdot (1 + P \cdot A_N)$$ Can Determine A_N if P is known and vice versa

If Polarization Normal to beam momentum:

$$P \cdot A_N \cdot \cos(\phi) = \epsilon(\phi) \equiv \frac{N_1(\phi) - N_2(\phi)}{N_1(\phi) + N_2(\phi)}$$

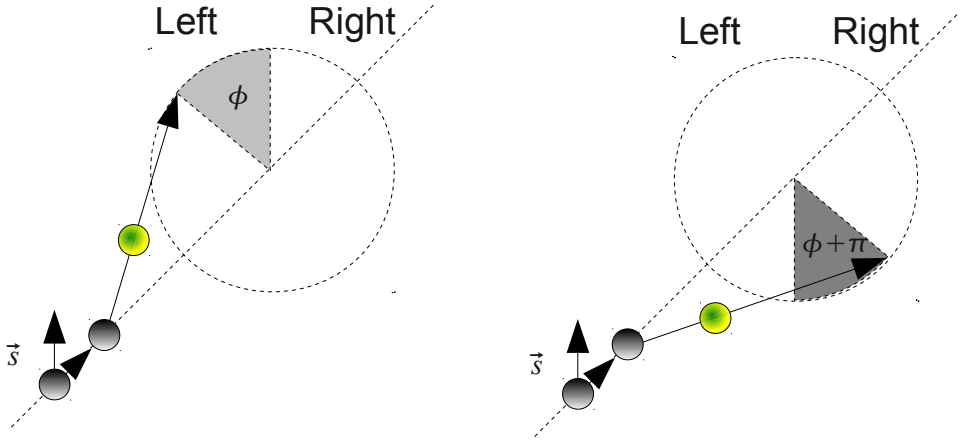
Polarization Asymmetry

$$\epsilon_{pol} = \frac{N^{\uparrow}(\phi) - N^{\downarrow}(\phi)}{N^{\uparrow}(\phi) + N^{\downarrow}(\phi)}$$



Left-Right Asymmetry

$$\epsilon^{\uparrow}_{LR} = \frac{N^{\uparrow}_L(\phi) - N^{\uparrow}_R(\phi+\pi)}{N^{\uparrow}_L(\phi) + N^{\uparrow}_R(\phi+\pi)}$$



PHENIX

$$\epsilon_{sqrt} = \frac{\sqrt{N^{\uparrow}_L(\phi) N^{\downarrow}_R(\phi+\pi)} - \sqrt{N^{\downarrow}_L(\phi) N^{\uparrow}_R(\phi+\pi)}}{\sqrt{N^{\uparrow}_L(\phi) N^{\downarrow}_R(\phi+\pi)} + \sqrt{N^{\downarrow}_L(\phi) N^{\uparrow}_R(\phi+\pi)}}$$

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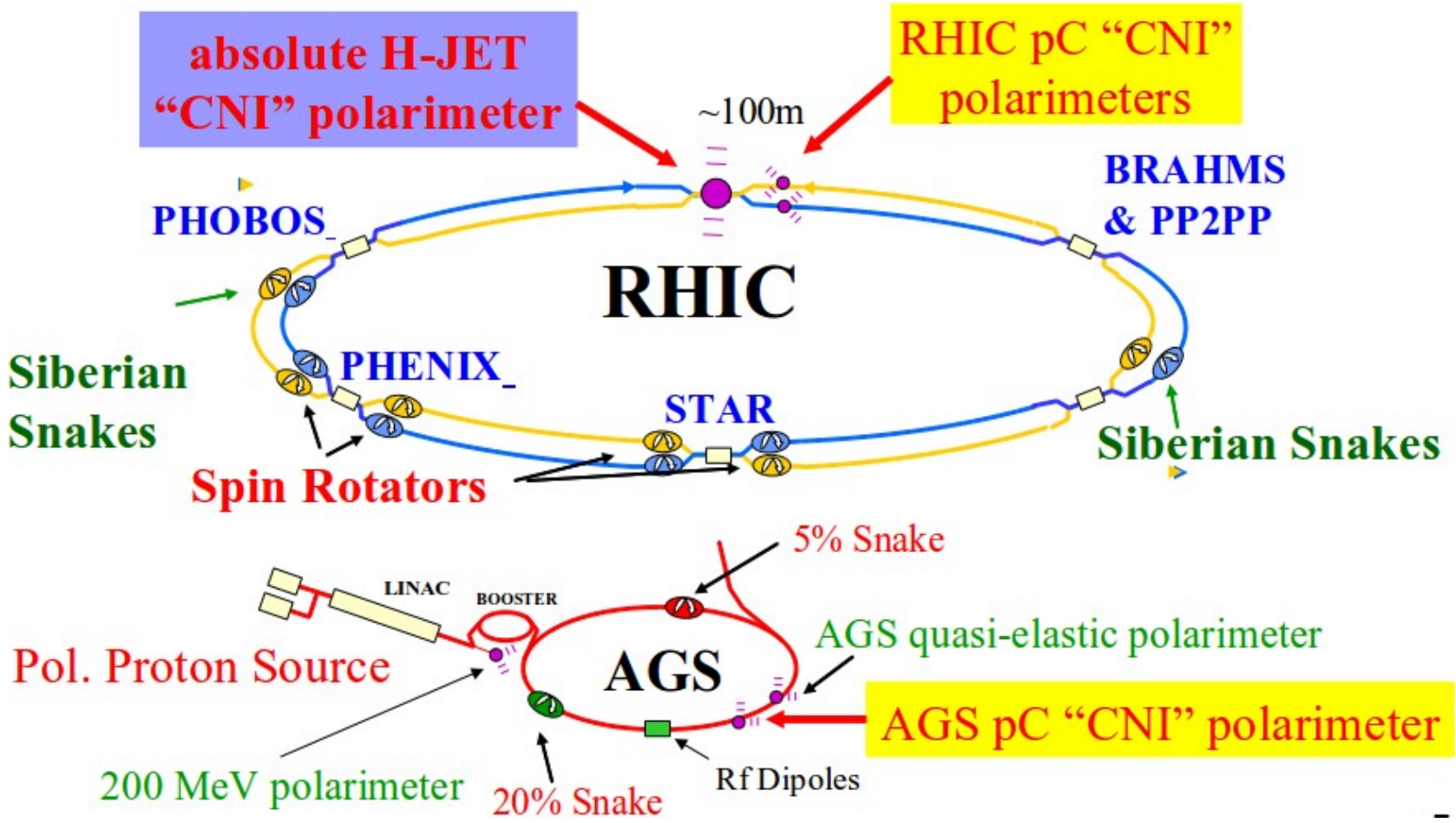
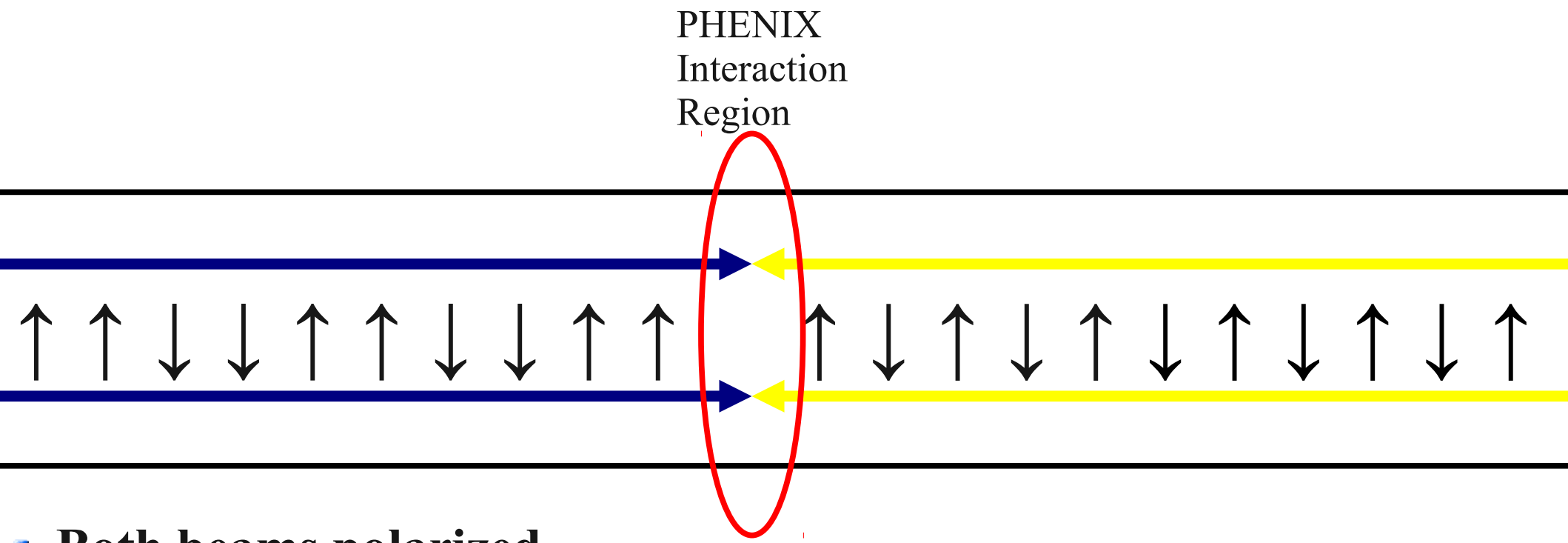
RHIC & AGS



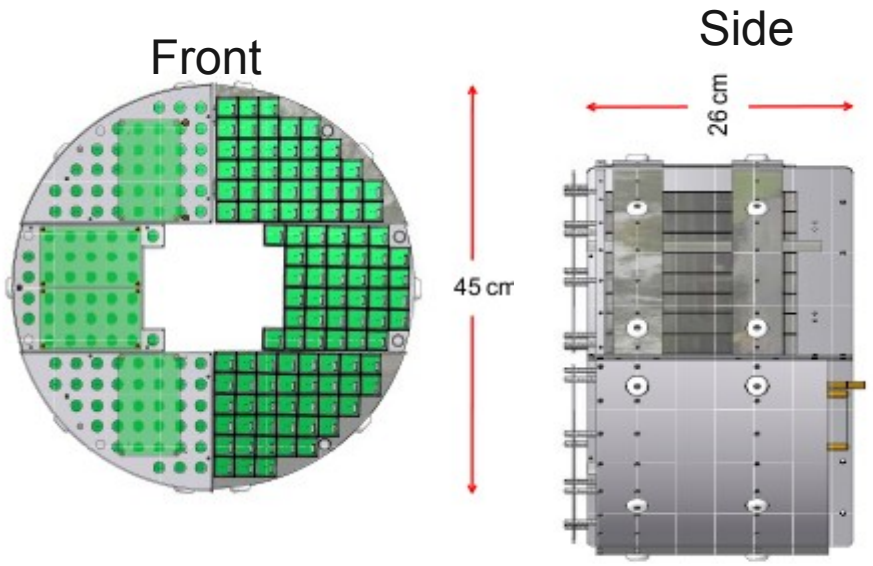
- Versatile Polarization: Longitudinal or Transverse (measured w/ CNI polarimeters)
  - Energies probed so far in p + p collisions $\sqrt{s}$=62GeV, 200GeV, 500GeV

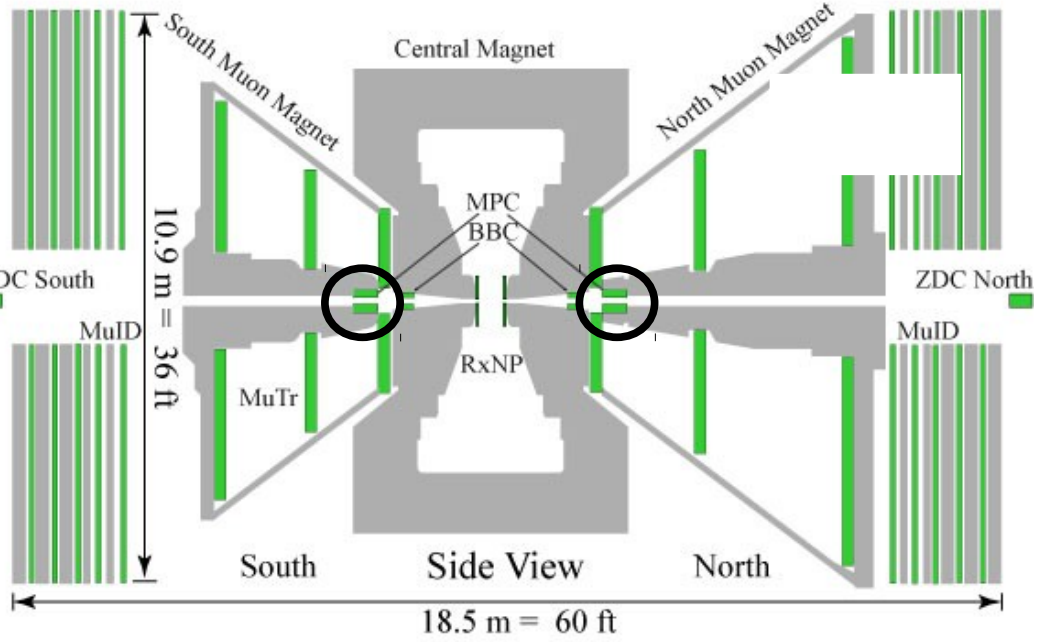
Polarized Beams



- **Both beams polarized**
- Variation of bunch polarization direction minimizes systematic uncertainties in measurement
- For transversely polarized beams, allows for two independent A_N measurements

MPC detector in PHENIX





- MPC is forward E.M. Calorimeter
  - 2.2x2.2x18 cm^3 $PbWO_4$ crystal towers
  - 220 cm from nominal interaction point
  - $|3.1| < \eta < |3.9|$

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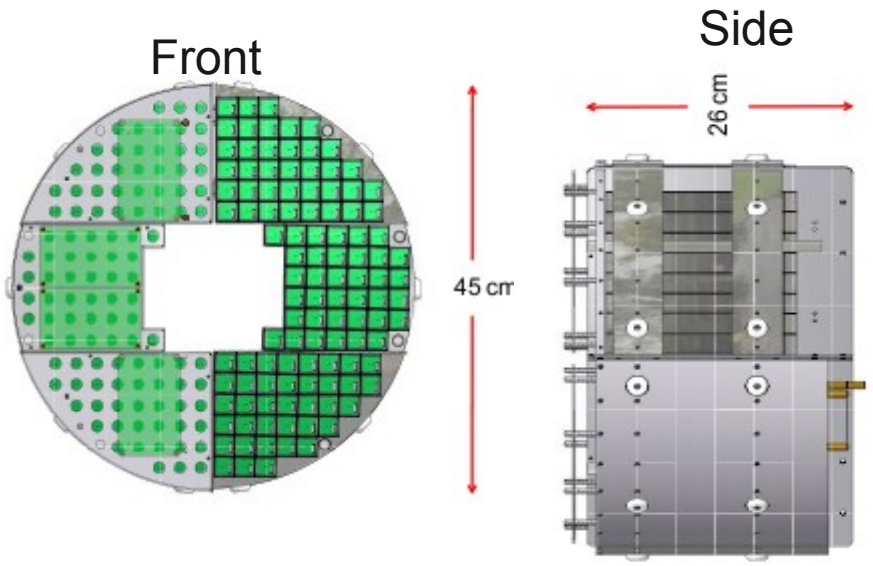

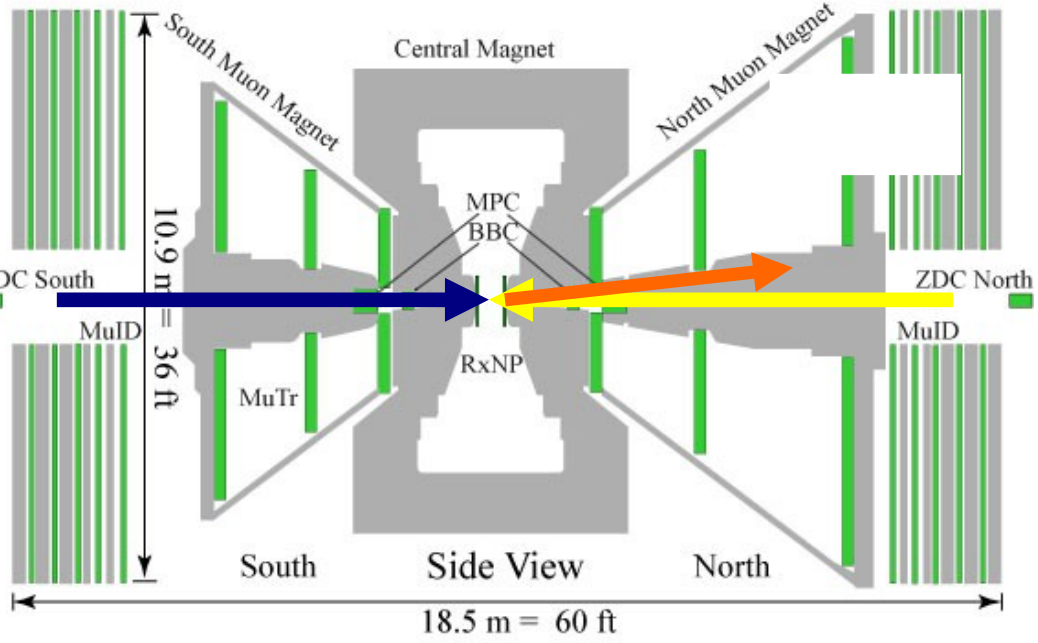

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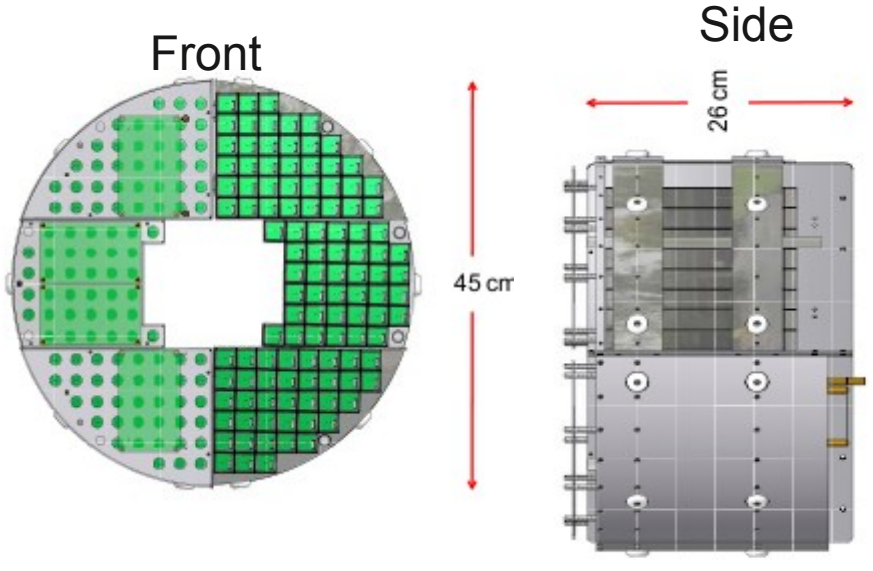

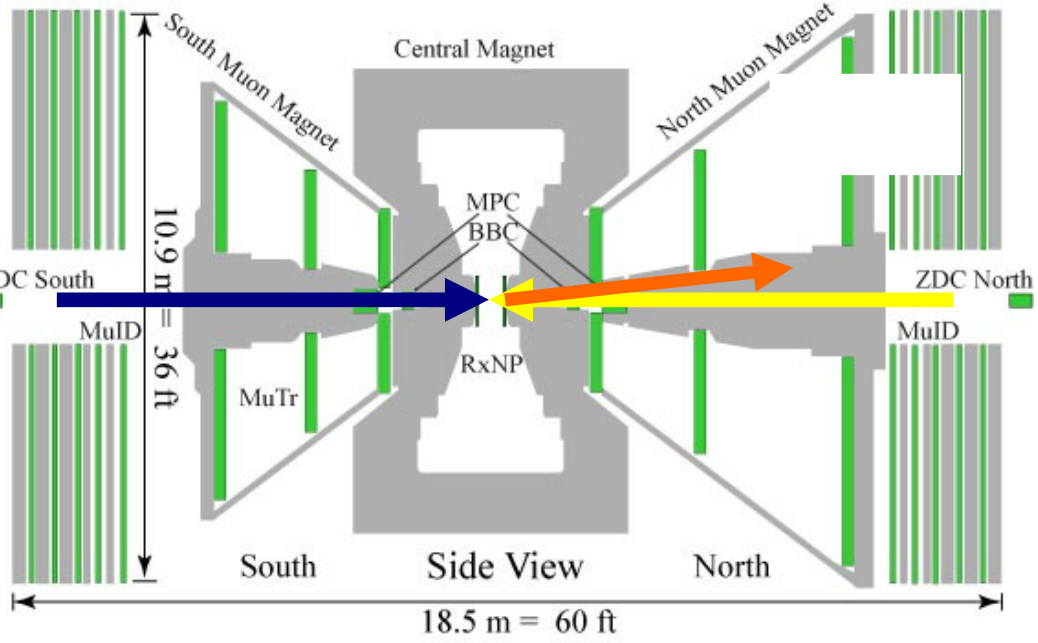

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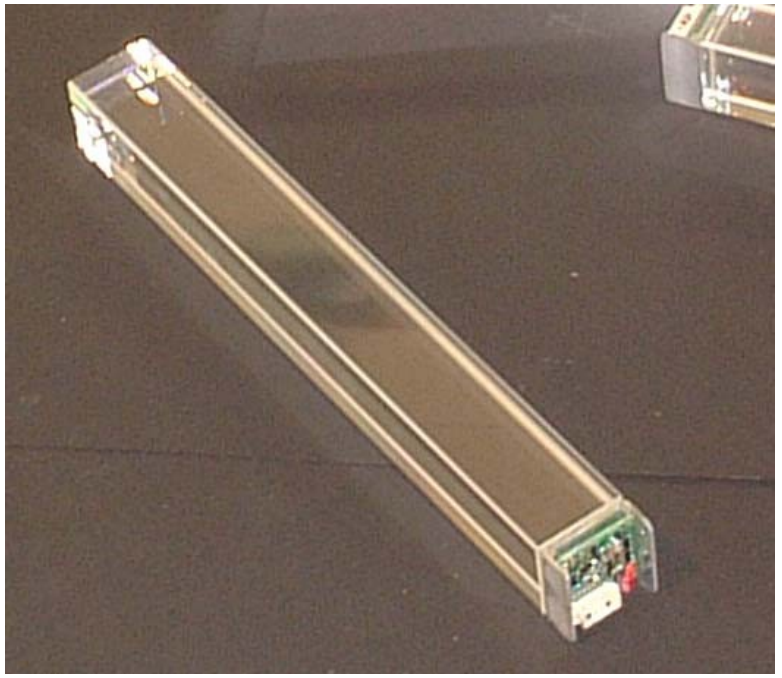
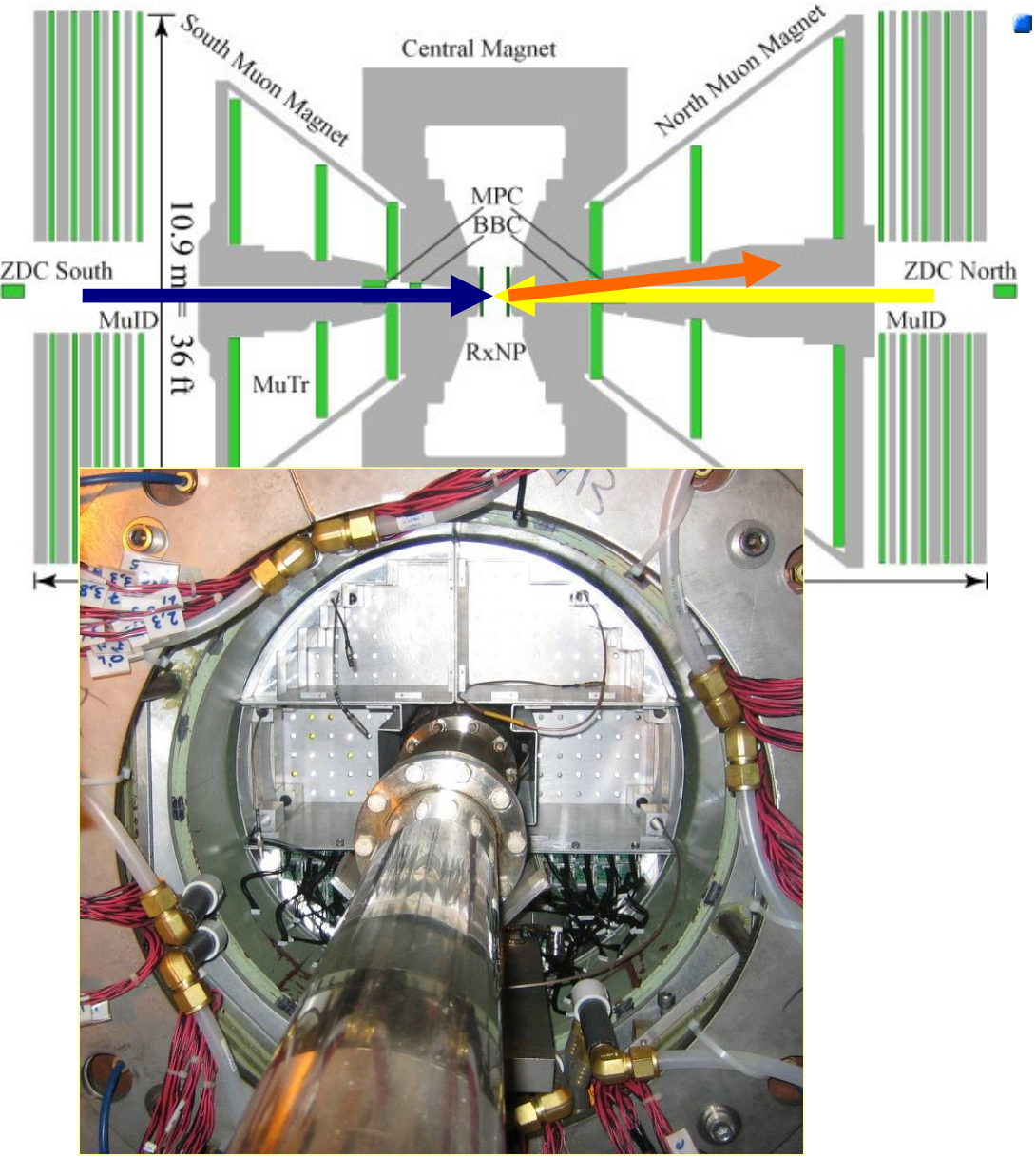


  - 196(220) crystals in south(north) MPC

Why use $PbWO_4$?



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  - Short Radiation Length (0.89 cm)
  - Small Moliere Radius (2.0 cm)

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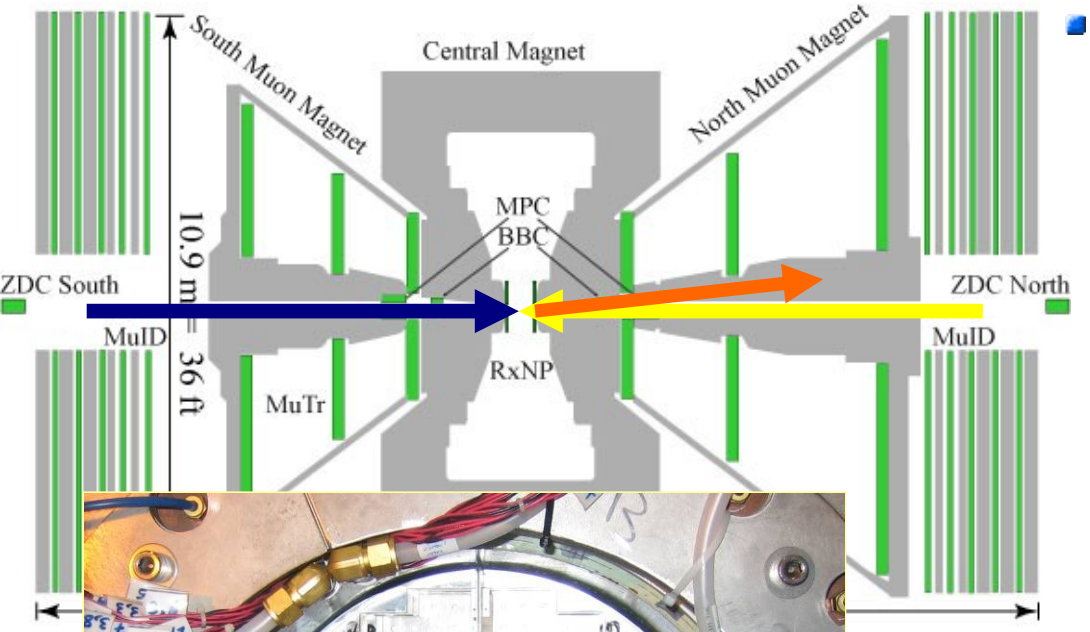

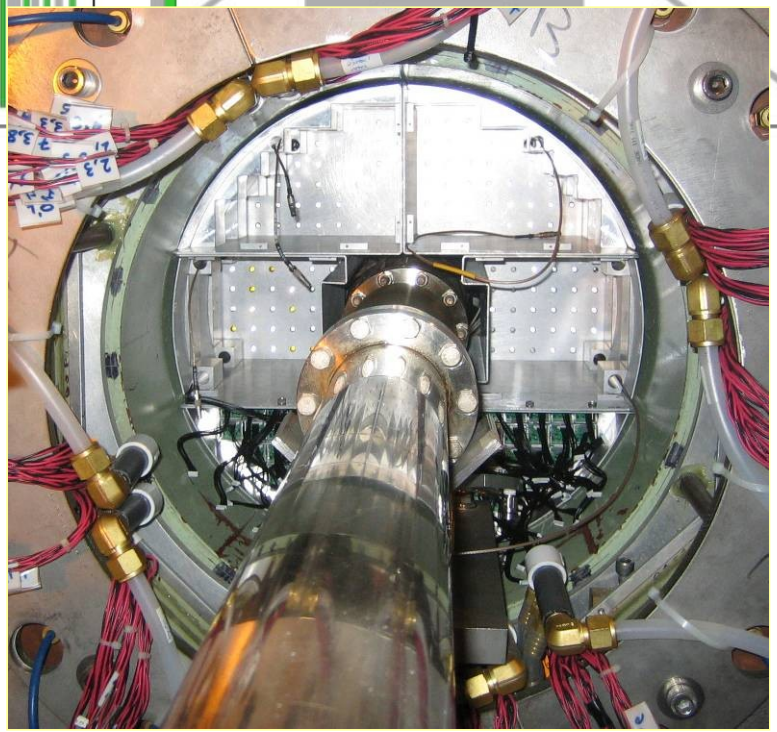

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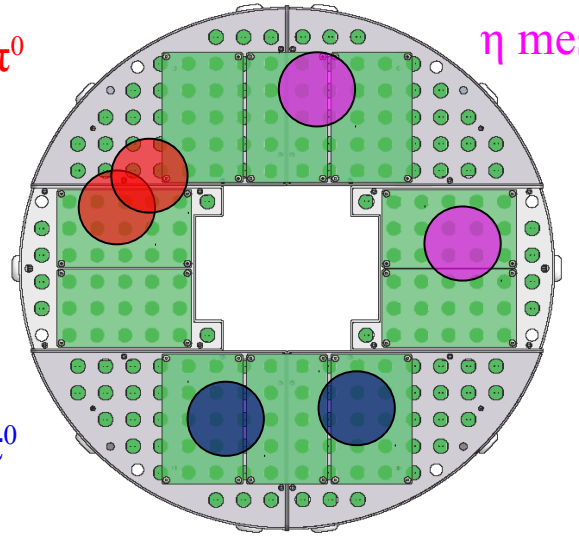
High Energy π^0

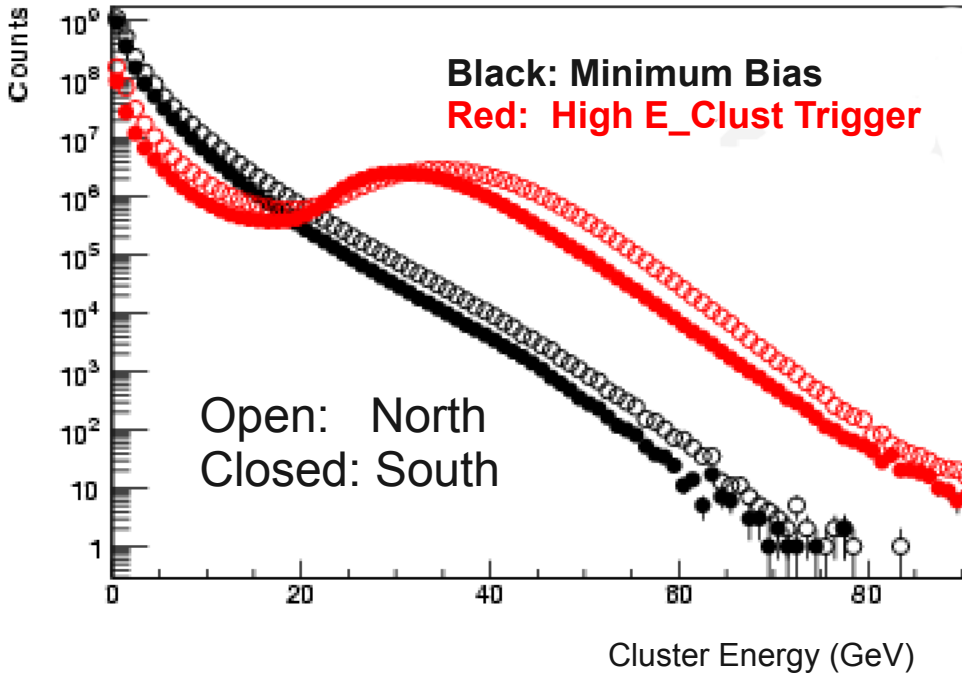
η mesons



Low Energy π^0

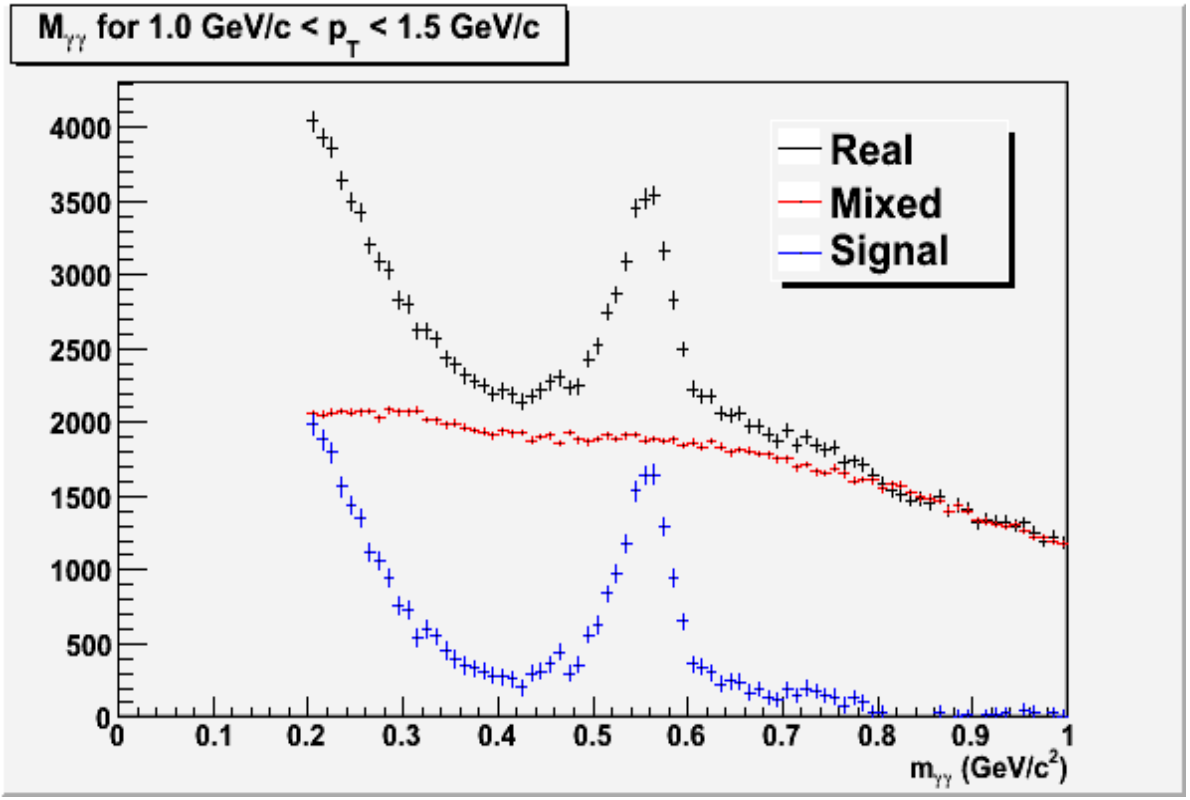
- Capable of reconstructing
  - η mesons (20 – 70 GeV)
  - Low Energy π^0 (7 - 17 GeV)
  - High Energy π^0 clusters (>17 GeV)
- **SEE TALK BY MICKEY CHIU ON MPC π^0 RESULTS**
  - **THURSDAY, SPIN IN HADRONIC REACTIONS 7**

High Energy Cluster Trigger



- Use high energy cuts on clusters, cluster pairs
  - Cluster Energy > 4.0 GeV
  - Pair Energy > 20.0 GeV
- Two Data sets used
  - Minimum Bias Event Trigger
  - High Energy Cluster Trigger
    - Live 4x4 tower energy sum > 20.0 GeV fires the trigger

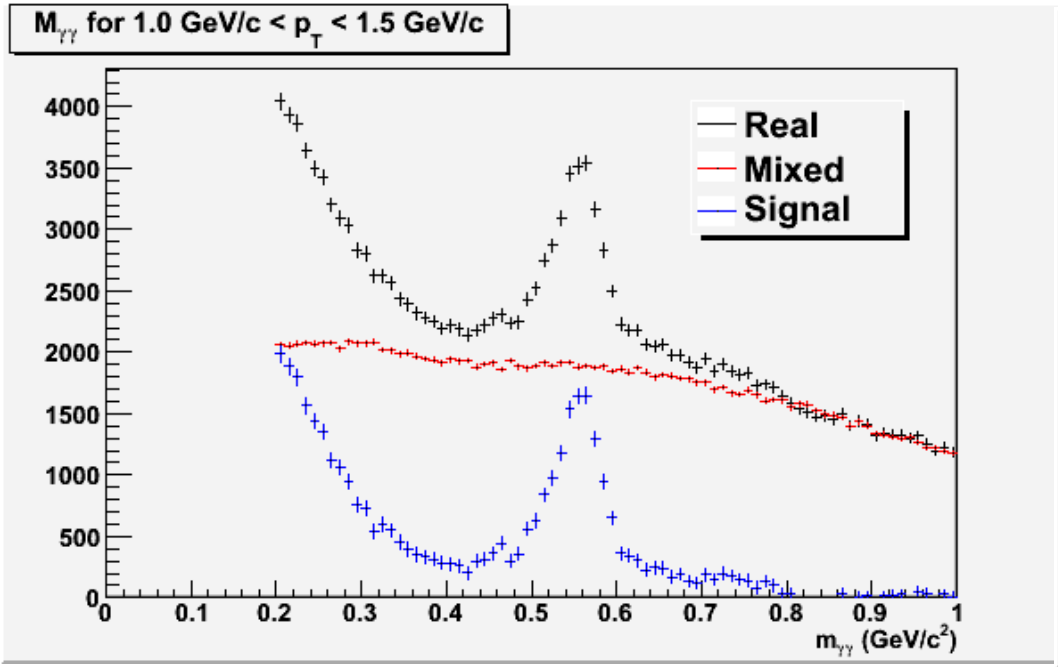
Extracting the η Meson Counts

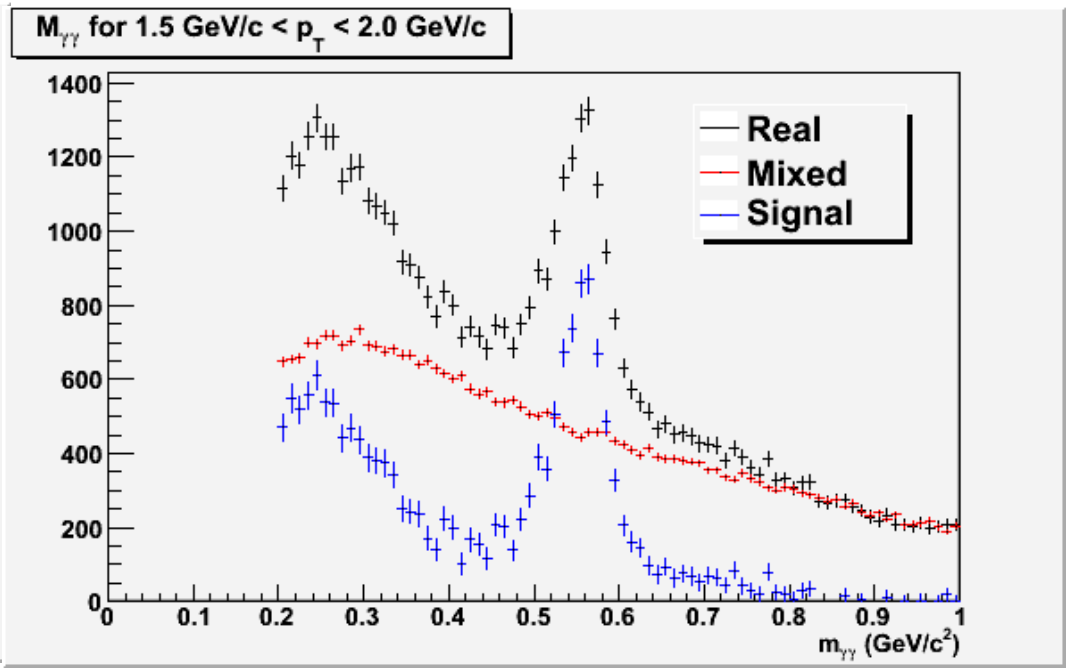


- *How do we remove the uncorrelated background?*
- Take the ratio **Real Pair Events/Mixed Pair Events**, and fit with constant, **C**
- Scale **Mixed Pair Events** by this Constant
- **Signal = Real Pairs – Scaled Mixed Pairs**

Mixed Event: Cluster pairing with clusters from two different events

Minimum Bias Event Data





- Clear Signal
- Correlated Background at 0.2-0.4 GeV/c^2
  - High energy π^0 Clusters (E > 20 GeV) merge, producing jet correlated background

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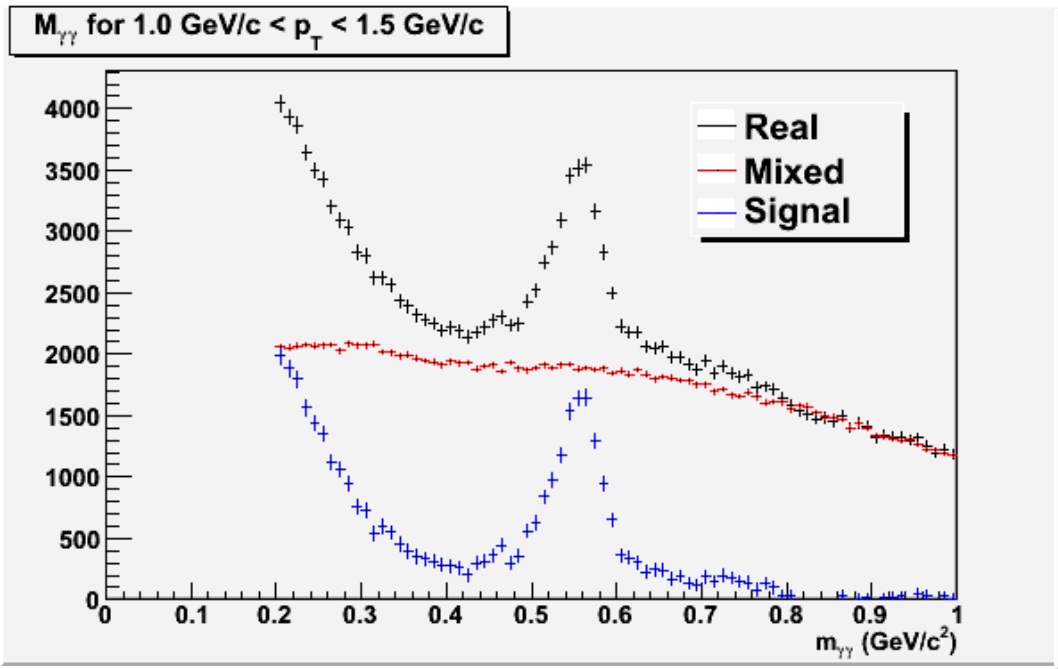

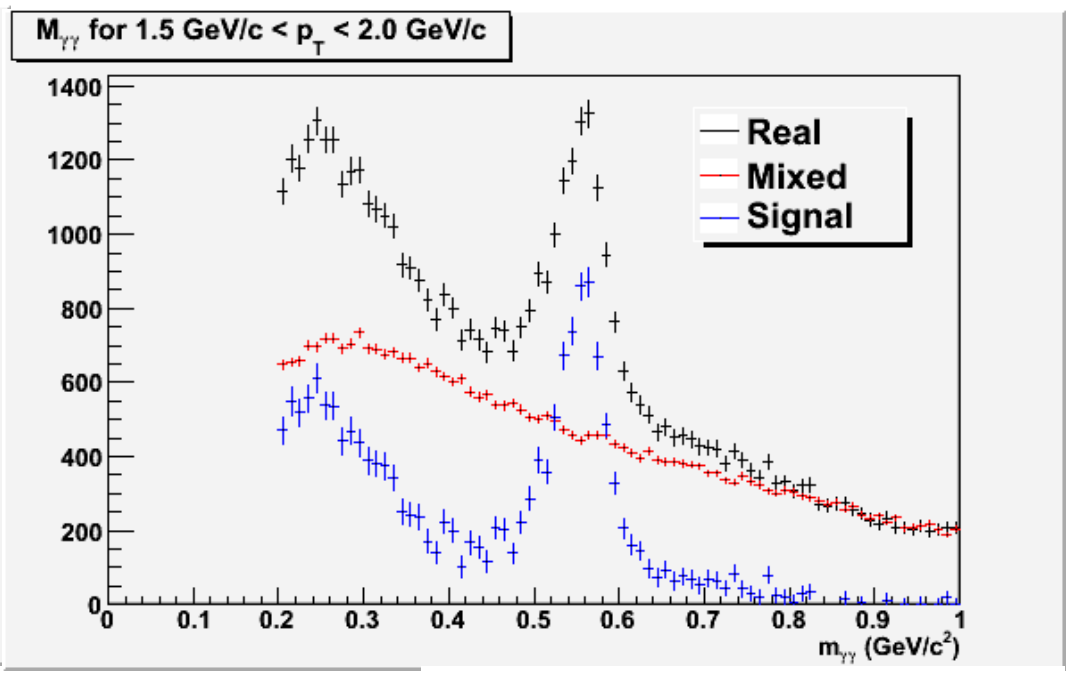

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High Energy π^0

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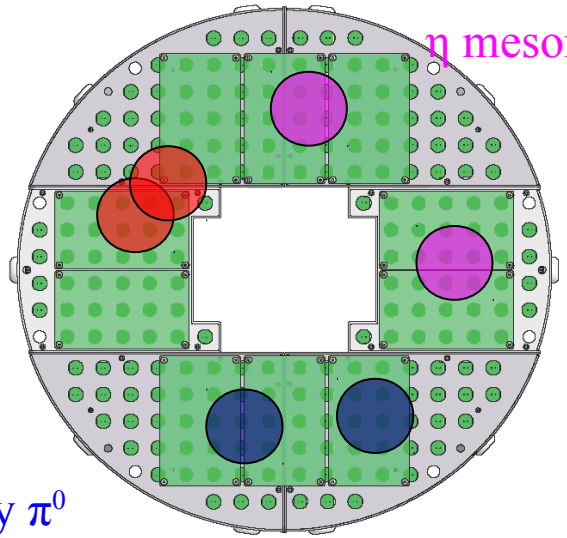
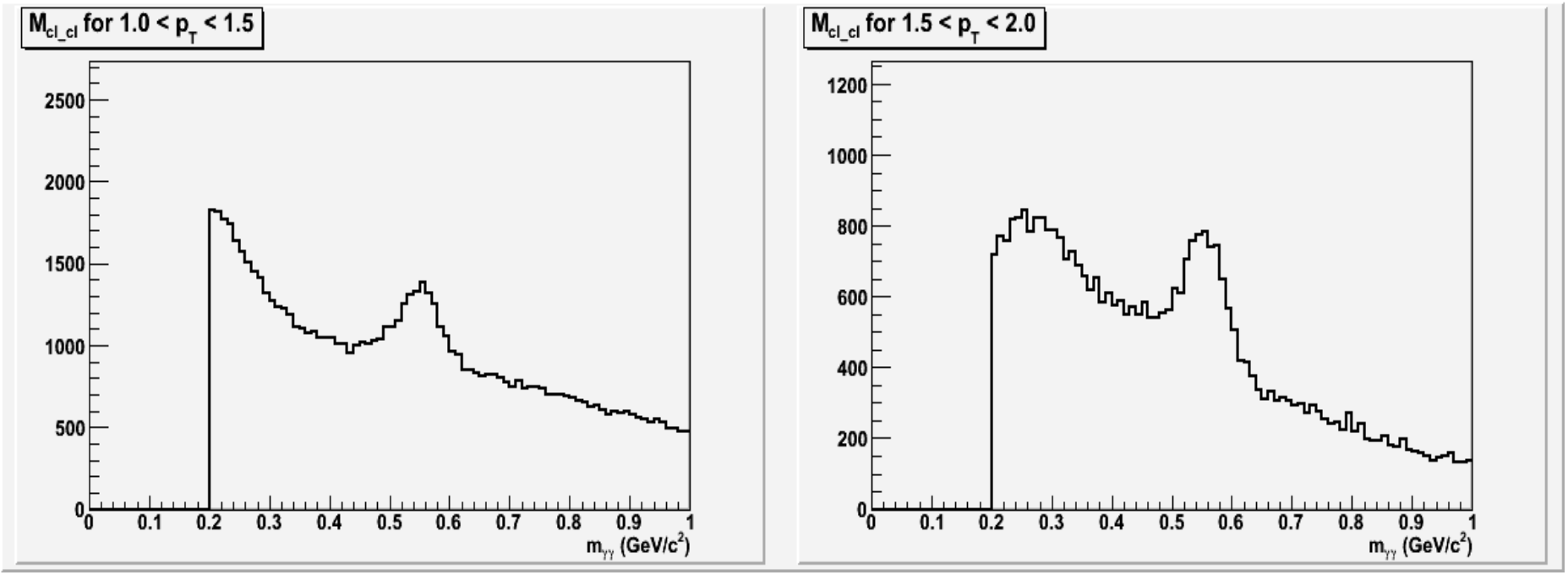


Low Energy π^0

(Minimum Bias) Data Compared to simulation



- ~90% of background from pairs where at least one cluster came from a π^0
- Need more detailed studies of simulation

Real Pairs (scaled to simulations)
Simulation Pairs
At least one cluster parent not from η
At least one cluster parent from a π^0
Both cluster parents from a π^0

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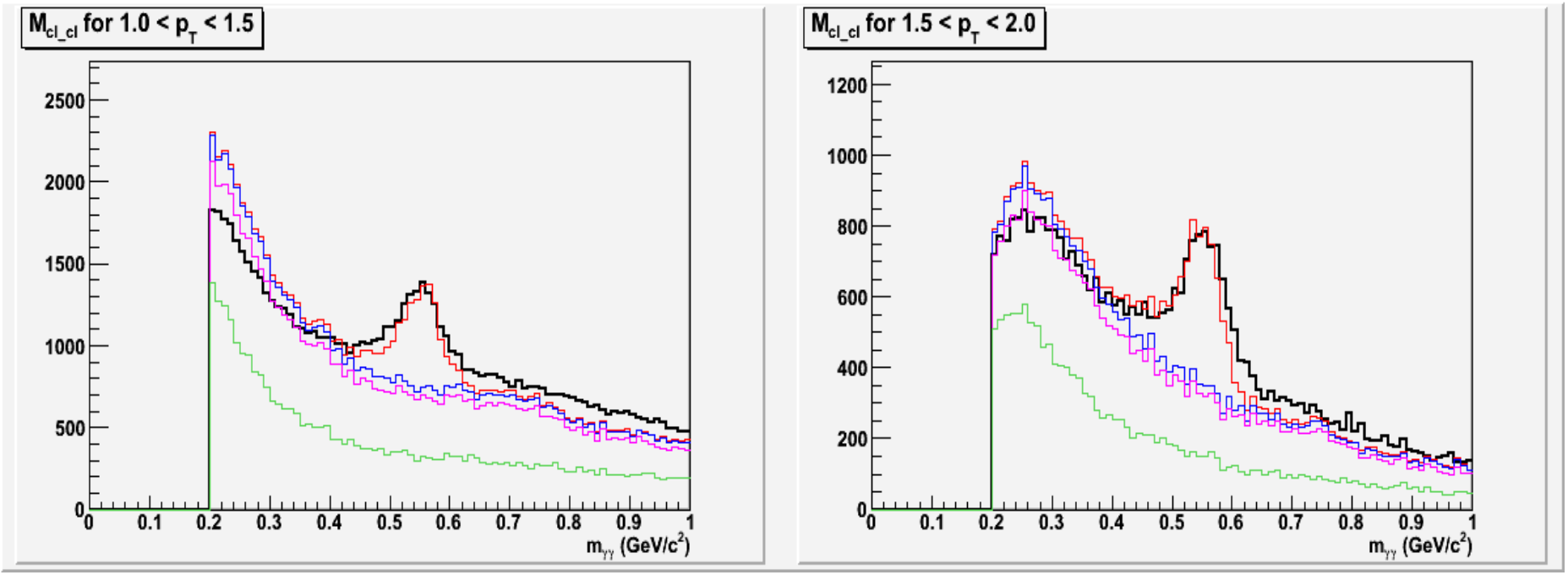

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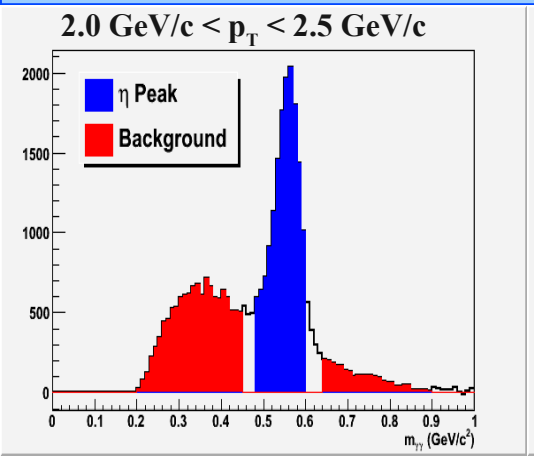
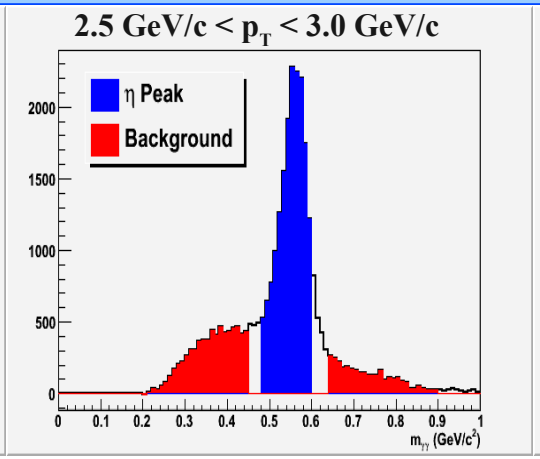
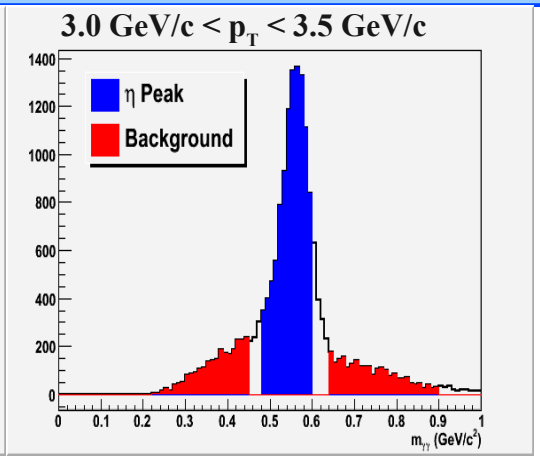
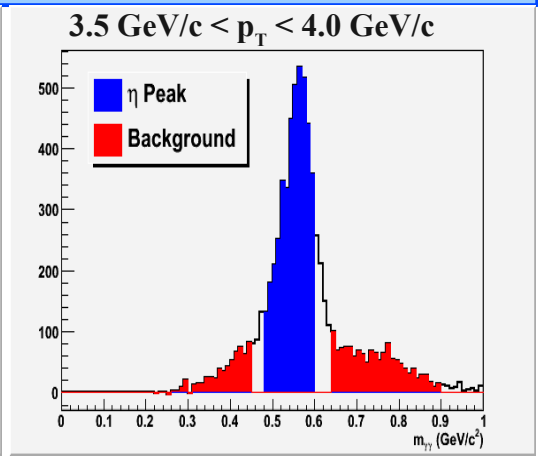






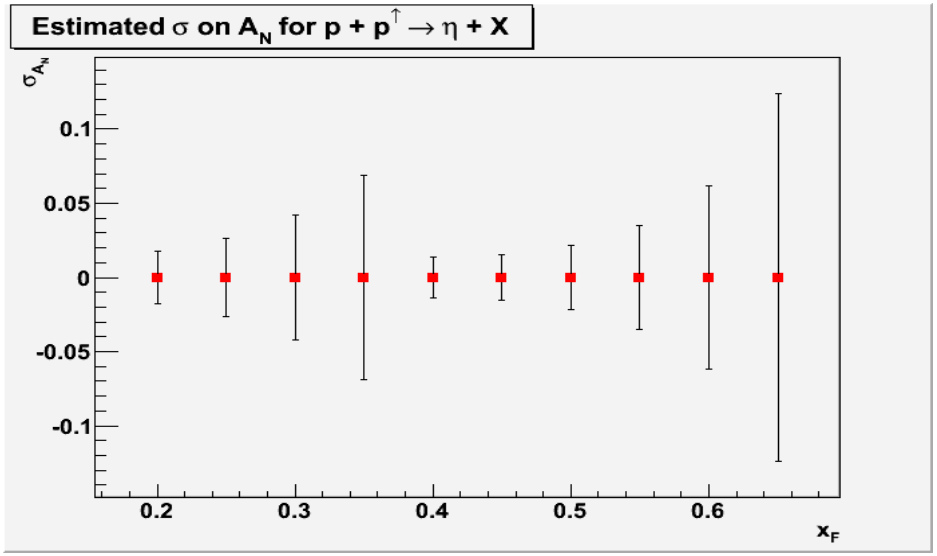


- Clear Signal, improved S/B at high p_T
- Correlated Background
  - Shifts to the right as energy increases
- Will do A_N of background.

$$A_N^{\eta} = r\,\frac{A_N^{peak} - r\,A_N^{bg}}{1-r}$$

Estimation of error on A_N

$$\sigma_{A_N} \sim \frac{1}{pol} \times \frac{1}{\sqrt{N}}$$



Minimum Bias Event Data	High Energy Trigger Data

- 2008 Run ($p+p^{\uparrow}$ at $\sqrt{s} = 200$GeV) at RHIC
  - 5.2 pb^{-1} integated luminosity
  - 45% vertical beam polarization
- Estimated Uncertainty
  - Statistical only
  - Does not take into account correlated background subtraction correction.

Summary and Outlook

We see a clear η meson peak in forward (backward) direction for $1.0 < p_T < 4.0$ GeV/c, $0.2 < x_F < 0.7$ in $\sqrt{s}$ = 200 GeV p+p$^{\uparrow}$ collisions

- North and South Arms will provide consistency checks
- Remaining Steps
  - Understand correlated background from Simulations
  - Calculate the foreground, background asymmetry
  - Calculate A_N in x_F, p_T
  - Calculate the cross section
- Expect results soon